Using the Abaqus BioRID-II Dummy to operationally support the development of a Front Seat Structure, focusing Low Speed Rear Impacts – evaluating Whiplash Risks

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Abstract

The importance of the seat in a low speed event has become increasingly more significant in recent years. To reduce the risk of neck injuries in low speed rear crashes, seat design is very important. The main task is that the seat absorbs energy in a controlled manner and gives support to the spine and the neck.

In high speed frontal crashes, the front airbag, the belt system including the belt pretensioner and the load limiter must work together in reducing the acceleration and to protect the occupant. In a low speed rear crash situation, the design and the performance of the backrest in combination with the head restraint system play a large role in protecting the occupant.

The BioRID-II rear impact dummy has been developed to measure the risk of whiplash injuries in low speed crashes. This dummy has been designed specifically to study the relative motion of the head and the torso. The BioRID-II dummy can help researchers learn more about how seatbacks, head restraints, and other vehicle characteristics influence the likelihood of the whiplash injury.

This paper describes a study of a BMW front seat model in low speed rear crash configuration using a finite element (FE) BioRID-II dummy developed by Simulia. The dummy was a preproduction version 1.9, without officially proved correlation of moments and rotations by FAT. In order to validate this FE model, hardware low speed tests have been performed. Furthermore an overview concerning the influence of the friction between dummy and seat, the influence of backset and the importance of the dummy position is presented.

Keywords: Whiplash Risk, Biorid Dummy, Rear Impact, Protection, Head Restraints

1. Whiplash

1.1 Phenomenon

The injury mechanisms of the so called whiplash phenomenon, which could occur in low speed rear end crashes, are not yet fully understood. From the biomechanical point of view, it is likely that such behaviour is caused by the relative motion between the head and the torso. The term “whiplash “ is used to describe these neck injuries. Injury to the human neck is a frequent consequence of car accidents and has been a significant public health problem for many years. The annual economic cost of “whiplash” injury in the European Union (EU) was estimated to be around 10 billion Euros [1]. In the United States the total annual socio-economic cost for soft tissue neck injuries has been estimated at more than $ 8 billion, based on the data from the Highway Loss Data Institute and the Insurance Research Council [2]. Whiplash is the most commonly reported injury in motor vehicle crashes. Research has shown that the seat design plays a major part in this topic. In order to help OEM ‘s and seat suppliers to reduce the injury risk during rear impact and hence the high costs for assurances, a special dummy was developed. The BioRID-II dummy is now widely use in the development phases of seats and head restraint systems.

1.2 BioRID-II Dummy

For many years hardware BioRID-II rear impact dummy has been used to evaluate the potential of car seats to protect their occupants. Several real sled tests have been performed to validate the real BioRID-II dummy. In order to save costs and to reduce sled tests during the development phase, a FE BioRID-II dummy has been specifically developed for Abaqus solver. The introduction of consumer tests, the rating of seats regarding whiplash performance and the focus on the development period makes the investigation of FE BioRID-II dummy important. In this paper the FE model of BioRID-II version 1.9 was used. Section 5 shows more details concerning general remarks on the BioRID-II dummy. The validated FE model of the seat was taken from the crash simulation.

2. Introduction to Seat

2.1 Selection of the Seat to be investigated

For the purposes of this investigation it was decided to concentrate on one seat. The seat, from the current BMW, was selected, because the seat has recently gone into series production and is therefore available at acceptable costs while also being at the leading edge in terms of the design and function.

2.2

2.3 Introduction to the Complete Seat and its Components

In order to satisfy the high demands on the seat system in the full vehicle, the finite element method today is a key tool used in the very early stages of the seat development process. Seat suppliers and vehicle manufacturers work hand-in-hand to optimize the seat design for functionality, stability and weight.

As a supplier of complete seat systems, Faurecia is increasingly responsible for the preparation and delivery of the validated complete seat models in defined stages to support this process. The complete seat structure, illustrated in Figure 1, comprises of metal, plastic and soft foam parts.

The head restraint, which is mounted directly on the top of the backrest, plays an important role in low and high speed rear impacts. In order to reduce the motion between the head and the torso, BMW has developed an active head restraint system. This study will explain the Whiplash performance of this complete seat design. To protect occupant during side impact this seat is also equipt with a thorax airbag system mounted directly on the side member of the backrest and under the seat foam/trim. As a complete seat system supplier, Faurecia has the responsibility to incorporate these components into the FE seat model in order to validate the complete system.

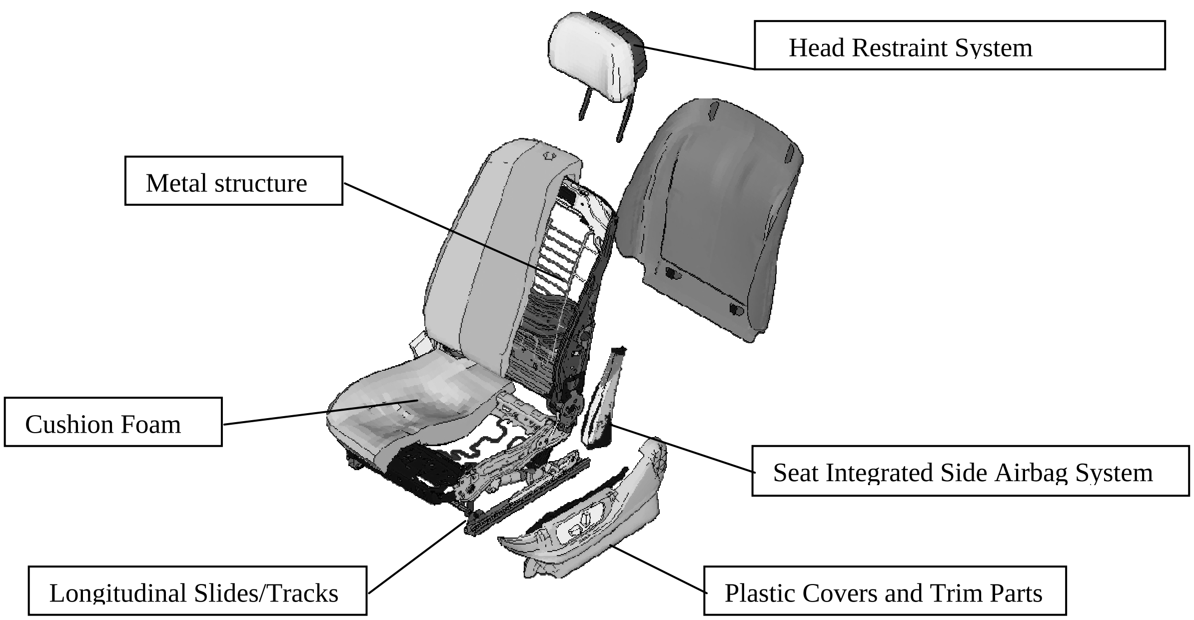


Figure 1. Complete seat finite element model

2.4 H-Point and SgRP-Point

The OEM deliver to the seat supplier a specific point [the SgRP Point] located in the vehicle in addition to a seat adjustment range. Faurecia applies several tools to optimize the adjustment range for a given population. Concerning the SgRP Point, the seat supplier has to ensure that the H-point [measured with the regulation comfort dummy , SAE J826 or its successor the HPM-II] is located in a defined field around this SgRP point. The H- point is measured on the pivot point between the torso line and the upper leg. [Figure 2].

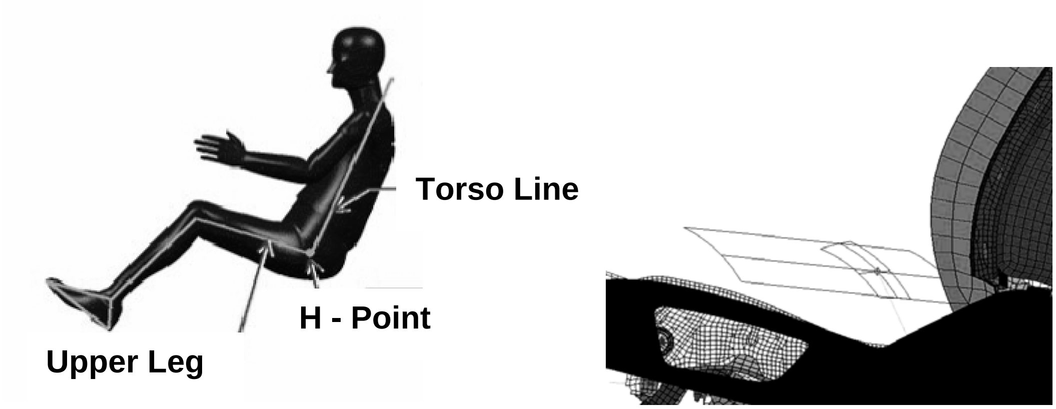


Figure 2. H - Point and SgRP

3. EuroNCAP Protocol

3.1 Dynamic Test Set Up

Since 2005 EuroNCAP has been developing its own rating system to enhance the occupant protection star rating system. Furthermore, the procedure was prepared to evaluate the way a seat and its head restraint system protect the neck against soft tissue injuries. The test procedure is designed for front seats only.

Insurance collision data suggests that the majority of all low-speed rear impacts where whiplash injuries occur take place at a difference of velocities of 16 km/h. However, the injuries occur with different velocities as well. Due to this fact, the procedure consists of three different sled tests, which simulate impacts at different delta-Vs.

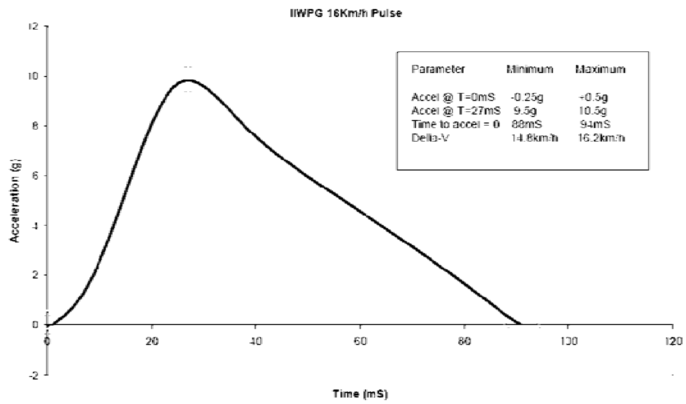


Figure 3. Medium sled pulse (triangular shape) - [4]

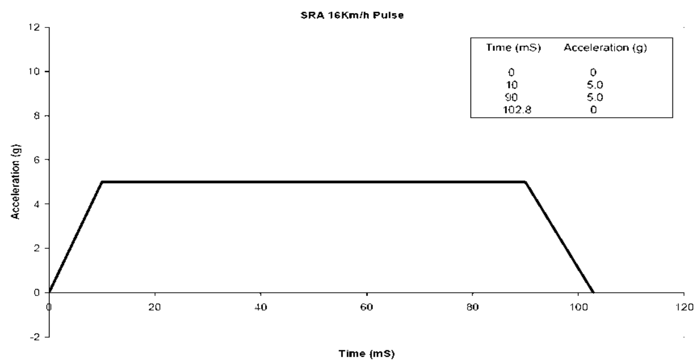


Figure 4. Low sled pulse (trapezoidal shape) - [4]

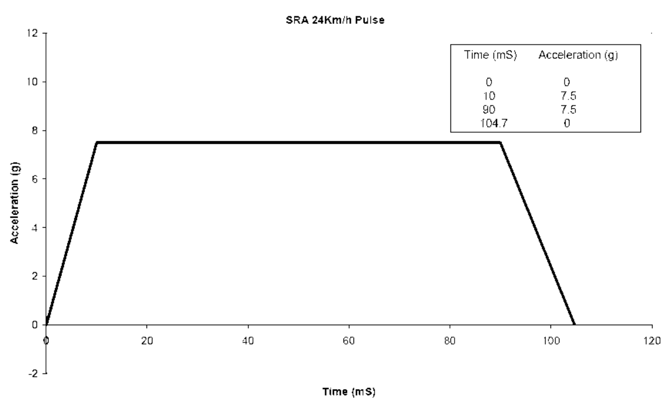


Figure 5. High sled pulse (trapezoidal shape) - [4]

The medium sled pulse (triangular pulse) was derived from Thatcham - insurance society's car-to-car tests; its delta-V is 16 km/h with 5.5 g mean acceleration. This pulse is adopted by IIWPG (International Insurance Whiplash Prevention Group) and by EuroNCAP. The other two pulses were trapezoidal and simulate a low and a high delta-V. The Low Severity Pulse (identical to SRA – Swedish Road Administration), has a delta-V of 16 km/h with 4.5 g mean acceleration [4]. The High Severity pulse (also identical to an SRA one) is supposed to prevent long term injuries [3]. The delta-V for the high severity pulse is 24 km/h and the mean acceleration is 7.5 g. All the three pulses are shown in Figures 3, 4 and 5. In summary, the EuroNCAP whiplash scheme uses a medium, a low and a high pulse [3],[4].

3.2 Criteria for Evaluation

The EuroNCAP protocol evaluates 6 out of 7 variables to assess the level of whiplash safety. In all the tests, as well as in all simulation runs, the following dummy channels and neck injury predictors were evaluated :

- **Head Restraint Contact Time** (HRC).Time of the first contact between the head and head restraint

  Disjunction

- **T1** X-Acceleration on the first thoracic vertebra
- **Upper Neck Shear Force**, positive value, +FX [N]
- **Upper Neck Tension Force**, FZ [N]
- **Head Rebound Velocity** (HRV)
- **NIC** relative horizontal acceleration and velocity of the occopital joint relative to T1 that means NIC considers the relative acc and vel between the head and torso. The NIC is calculated according to formula 1.

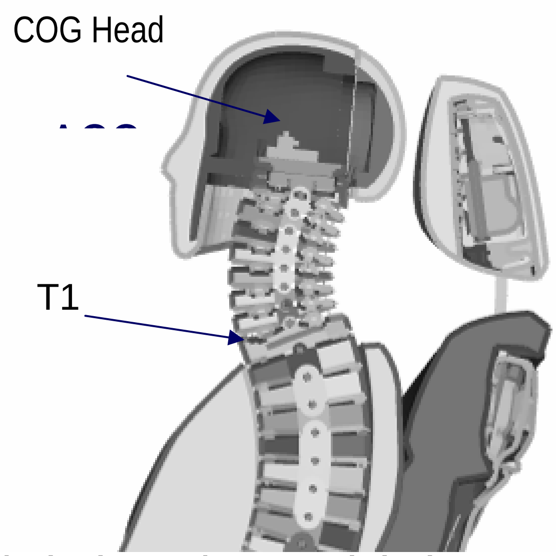


Figure 6. Biorid Variables

$$NIC = a_{relative} \cdot 0{,}2 + v_{relative}^2 \qquad (1)$$

- **N$_{km}$** combination of moment and shear force. The N_{km} is calculated according to formula 2.

$$Nkm(t) = \frac{Fx(t)}{F_{\text{int}}} + \frac{Moc_y(t)}{M_{\text{int}}} \qquad (2)$$

Figure 6 shows an overview of the accelerometer positions in the head and in the cervical vertebra. Every variable has a range, defined by Upper and Lower Limit values, as also the Capping value, which allow to distribute the appropriate score. You will find some more details concerning all the variables in the EuroNCAP protocol [3]. The scheme also introduces four modifiers to the scoring: geometry, vertical locking, ease of adjustment (usability) and dummy artifact [4]. For more information please refer to EuroNCAP protocol [3].

Three separate pulses plus seven variables and additional scoring modifiers make the EuroNCAP assessment rather complex. Figure 7 shows the whole procedure for EuroNCAP assessment. The procedure is still under development and subject to change. The scoring scheme and scale are not yet finalized [4].

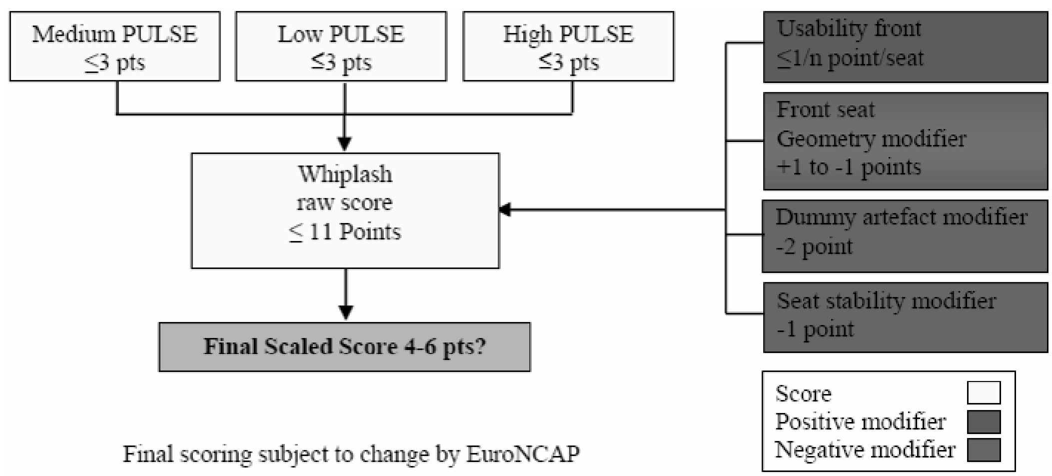


Figure 7. EuroNCAP Whiplash Scheme

3.3 Position of the Seat Structure

The protocol requires well calibrated sled instrumentation to measure accelerations. It also requires a high speed camera with several targets on the seat and on a BioRID-II dummy to measure some of the variables like head rebound velocity or seat dynamic opening. The most important targets are placed on the head, the torso and the pelvis of the dummy, as well as at the main construction points of the seat and the head restraint system. The instrumentation of the BioRID-II has to be calibrated as well.

The seat and the head restraint system adjustments are described in detail in the EuroNCAP procedure [3]. The important are:

- Seat is in the same position against the sled as in the real car (height and rail angle), as well as the method of mounting
- The toe board is at an angle of 45 degrees and is at the same distance to the seat as the acceleration pedal
- Seat track (longitudinal) adjustment should be set to middle position, if available
- Seat height adjustment (if available) should be set to middle position
- Seat tilt adjustment (if available) should be set to most possible horizontal position
- Head restraint device should be set to middle position (if possible)

For the detailed procedure of all the settings**,** please refer to the EuroNCAP protocol [3]. Figure 8 shows the seat and BioRID-II in EuroNCAP Position

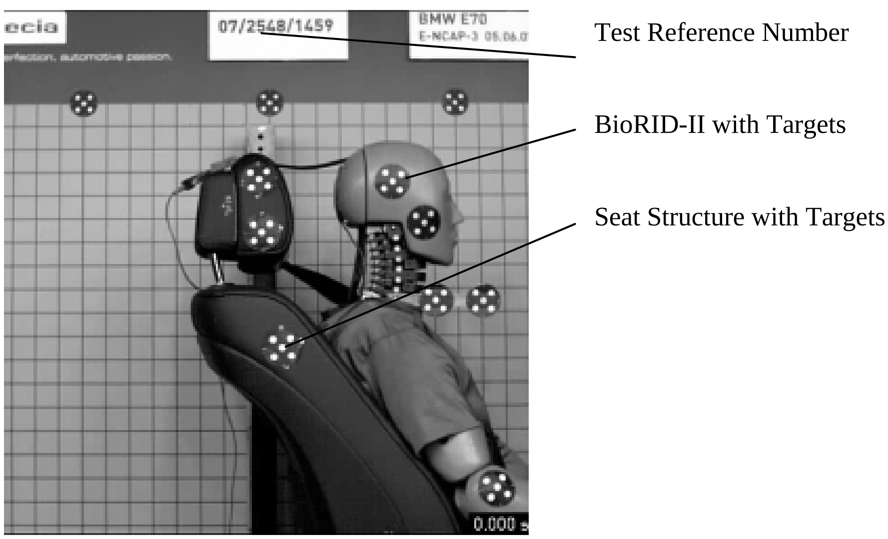


Figure 8. BioRID-II EuroNCAP Position

4. BioRID-II Dummy behavior – general remarks

The BioRID-II dummy has been developed to mimic the behavior of the human spine in the best possible manner. The legs and arms of a BioRID-II dummy are the same as of a Hybrid III dummy. The pelvis, the torso and particularly the spine are exclusively used for the BioRID-II dummy.

The new component of the BioRID-II dummy is a fully articulated spine assembly, consisting of lumbar, thoracic and cervical vertebrae, anterior and posterior bumpers and stoppers, lumbar and thoracic washers and adjustment washers, muscle substitute cables, occipital interface, rotary dumper drum and damper cables~~.~~ The model of spine assembly and its comparison to the real spine is shown in Figure 9.

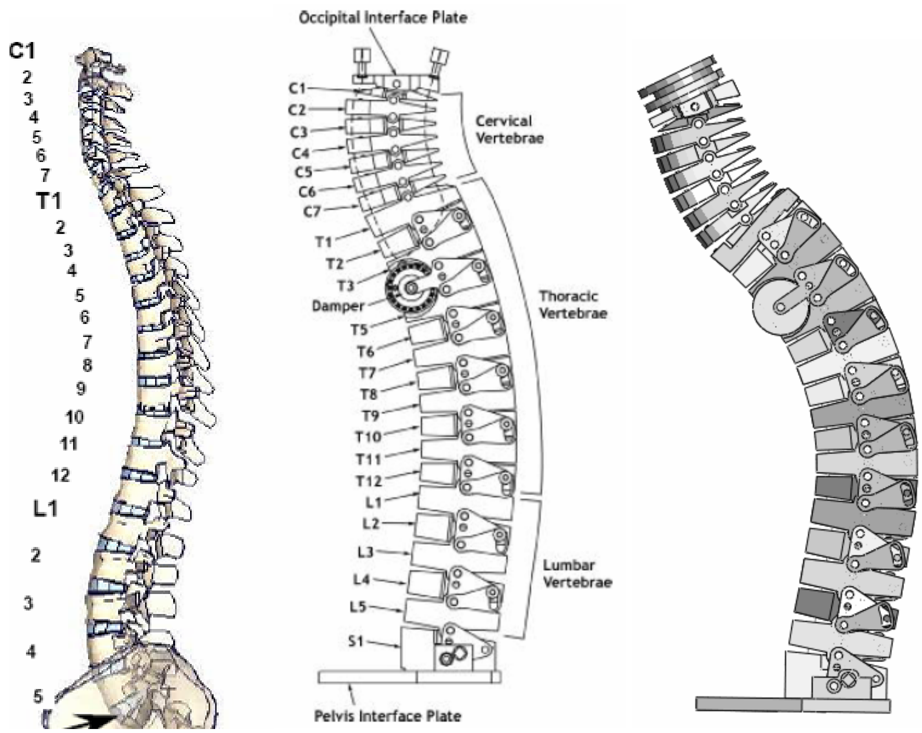
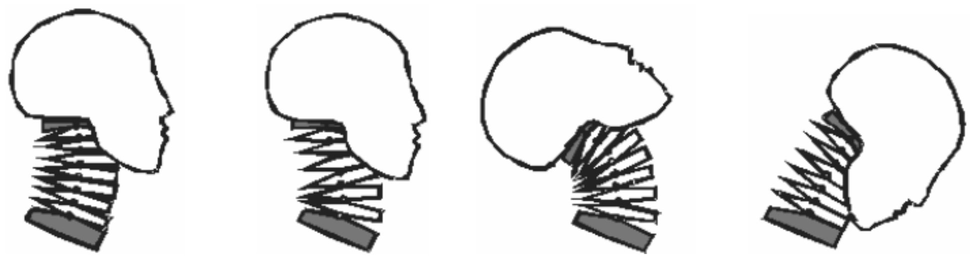


Figure 9. Comparison of the human spine and the BioRID-II dummy's spine (hardware drawing and FE model) – [6], [7]

A complex model is necessary to capture the rear impact behavior correctly. There are three main phases during rear impact, when the spine in the cervical vertebrae is particularly vulnerable to injuries. These are: S-shape, Extension and Flexion, shown in Figure 10.

In the first phase the pelvis is caught by the lower backrest, then the upper thorax is pushed forward in the shoulder area by the seat back, while the occupant 's head, due to its inertia, remains at its original location in space, since it is not in contact with any parts of the car. In this phase the head does not rotate and therefore together with the purely translational forward motion of the thoracic column, the upper cervical spine is forced into a flexion and the lower cervical spine into an extension. This S - shaped deformation of the cervical spine has been observed in experiments with special dummy necks as well as in volunteer tests.

SIMULIA has developed an FE Abaqus BioRID-II dummy model, which fully corresponds to the real dummy and includes all of its functionalities.



Original (phase 1) → S-Shape (phase 2) → Extension (phase 3) → Flexion (phase 4)

Figure 10. Phases of the neck deflection – [6]

5. Positioning of the Hardware and Virtual BioRID-II dummies

Proper BioRID-II dummy positioning procedure is a key step to obtain proper experimental or simulation results. The procedure should be the same in both cases, however it may be simplified in simulation to reduce the computational time.

5.1 Positioning of the BioRID-II dummy in a real test

Positioning of the BioRID-II dummy consists of two phases. In the first phase, the seat has to be set as described in section 3. To get the proper values for the BioRID-II dummy, an H-point machine (SAE J826) with HRMD (Head Restraint Measurement Device) has to be seated first. The machine measures the H-point position, but it is also used to set the upper seatback angle to get the torso angle of 25 degrees. When this settlement is done, the backset and the offset have to be measured (shown in Figure 11).

The second phase consists of the positioning of the BioRID-II dummy, with taking all of the previously measured values with HRMD as reference ones, with some changes. The pelvis angle should be set to 26.5 degrees, and the H-point coordinates should be taken adding +20 mm in X direction and at the same Z-height, in comparison to SAE J826 measurements, considering the car's main axes.

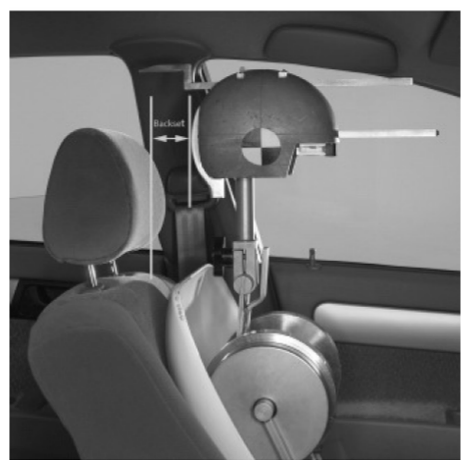


Figure 11. SAE J826 dummy with HRMD installed – measurement of the backset

When setting the backset, the head has to remain horizontal within a tolerance of ±1 degree. Furthermore the backset of the BioRID-II dummy manikin has to be measured. BioRID-II dummy's backset should be the reference backset plus 15 mm (within ± 5 mm). The spacing between the legs should be adjusted in such a way that the centerline of the knees and ankles is 200 mm apart [3]. For more details please refer to EuroNCAP protocol [3].

5.2 Positioning the virtual BioRID-II for test fitting

The main task in this case is to fit it to the test conditions. The simulation is done after making the real experiment to validate the FE model for further project iterations. Thanks to making the test a priori, a complete set of all measurements needed to position the dummy is available. These are: H-Point, heel point, knee point, backrest angle, backset and offset.

To optimze the whole process and to decrease the CPU time, the positioning procedure is divided into several separate parts:

1) Correct positioning of the seat in a preprocessor to achieve the same target positions as in the sled test simulation.

2) Positioning of the dummy in a preprocessor. The dummy should be placed in the H-point coordinates obtained in the test. Also the pelvis angle and the heel point should be set.

3) To get correct values for the stresses and forces in the spine, it is necessary to set the correct head angle and offset in a separate simulation with the dummy only, but with fixed position of the pelvis. Gravity load should also be applied.

4) To have a proper interaction between the seat and the dummy, it is necessary to place the dummy in the seat. To decrease the computational cost, a rigid dummy (with the shape obtained in step 3) is positioned in the seat. The values of stresses in the foam have to be exported to the final crash simulation

For the final crash simulation a combination of data has to be taken. Seat frame and foam, with initial stresses has to be obtained from step 4. Dummy data with initial stresses in the spine has to be obtained from step 3.

5.3 Positioning the virtual BioRID-II for early design phases

When considering typical simulation activities in early design phase, no test data is available. Hence, the positioning procedure should be performed in the same way as described in the EuroNCAP procedure.

The positioning procedure is divided into various phases, the same as for test fitting.

1) Positioning of the virtual seat in a preprocessor as desribed in EuroNCAP protocol.

2) Simulation with SAE J826 dummy with HRMD installed to achieve 25 degrees of torso angle made by backrest angle adjustment.Backset is an output data of this simulation.

3) Positioning of the BioRID-II dummy in a preprocessor. The dummy should be set in the H-point +20 mm, obtained in previous SAE J826 simulation, with pelvis angle of 26.5 degrees and theoretical heel point.

4) To reach backset obtained in Step 2, a simulation with the BioRID-II dummy is required. A gravity load also needs to be applied. The backset value should be set to a value obtained during HRMD simulation + 15 mm (the backset measured for HRMD is different than for the BioRID-II dummy). The values of stresses in the spine have to be exported.

5) To get the proper seat initial deformation, a simulation with rigid dummy positioning is necessary. The dummy shape should be obtained from step 4.

6. Comparison – hardware sled test versus simulation

For such complex test conditions and simulation models, it is necessary to validate both the seat and the dummy. The dummy has been validated by SIMULIA. The model is developed by ABAQUS in cooperation with German Association for Research in Automobile Technology FAT ("the BioRID working group").The validation phase for this work has been done on simplified seat from Chalmers University [11].

6.1 High speed rear impact

The validation of the seat has been performed in high speed rear impact conditions. The test was made according to old FMVSS301 regulation, using the Hybrid III 50 percentile dummy. The seat was in the powered basis configuration, the same as for the planned Whiplash analysis. The seat position was set up to: frontmost in longitudinal adjustment, upmost in height adjustment and downmost in tilt adjustment.

As as validation criterium for this test versus simulation fitting backrest dynamic deflection angle has been chosen. Compared to our single refernce test difference was below 2 degrees[9].

6.2 Side impact

The seat has also been validated under side impact conditions, where the stiffness of the seat frame was validated using a drop tower facility. The detailed description is available in [5].

6.3 EuroNCAP High severity case validation

In the EuroNCAP scheme three cases of different severity are required for each seat evaluated. For low speed impact validation a high severity pulse was chosen, since this pulse is the most demanding for the seat and for the head restraint system. A real hardware simulation was done with a complete set of measurements, both for the dummy and the seat.

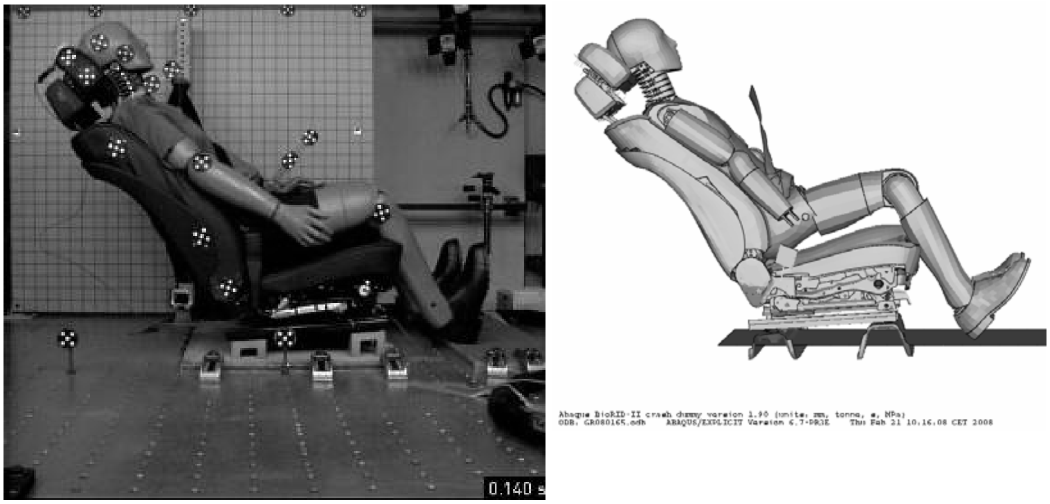


Figure 12. Comparison of EuroNCAP valid

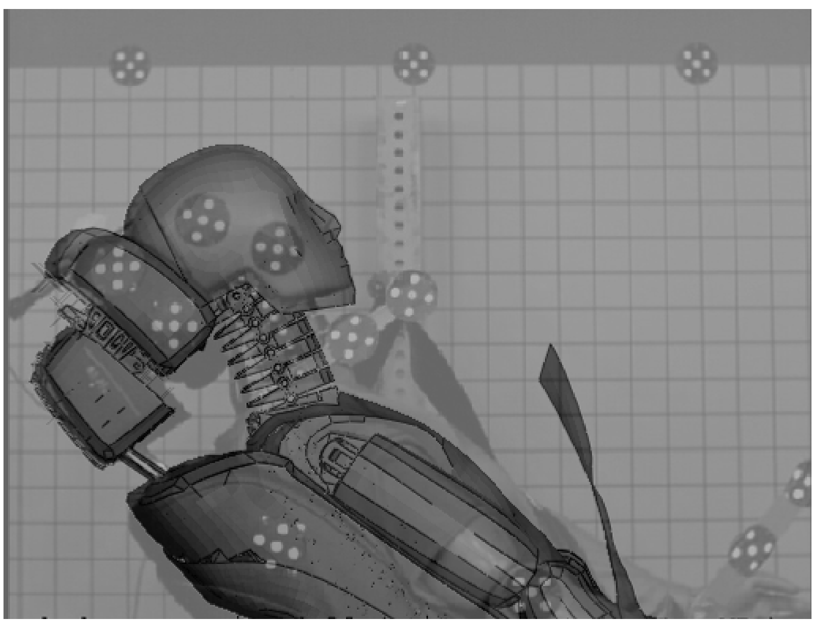


Figure 13. Direct comparison between test movie and simulation at maximum deflection.

Variable	Test	Simulation	Difference	Difference in %
Head Restraint Contact Time	2.56	2.56	0	0.0
T1 X-acceleration	0.69	0.66	-0.03	-4.3
Upper Neck Shear Force	0.004	0.0046	+0.0006	+15
Upper Neck Tension Force	0.56	0.82	+26	+47.1
Head Rebound Velocity	0.77	0.84	+0.07	+9.7
NIC	0.90	0.83	-0.07	-7.7

Table 1. Comparison of the BioRID-II dummy output variables between hardware test and virtual simulation. All variables come from the EuroNCAP protocol [Version 2.6]. All variables have been normalized.

The pulse used in the simulation was identical to the one used in the real test. Figure 14 shows the comparison of the pulse with the theoretical one.

The simulation seat model was repositioned to fit the test measurements. The dummy was positioned according to the procedure described in section 5.2

To assess the correlation, two main criteria were used:

- Visual assessment of the dummy and the seat behavior done by super position of test movie and Abaqus simulation.
- Numerical assessment – accelerations, velocities, forces and moments measured on the dummy and on the seat with accelerometers and film analysis. Additionally EuroNCAP variables were also computed.

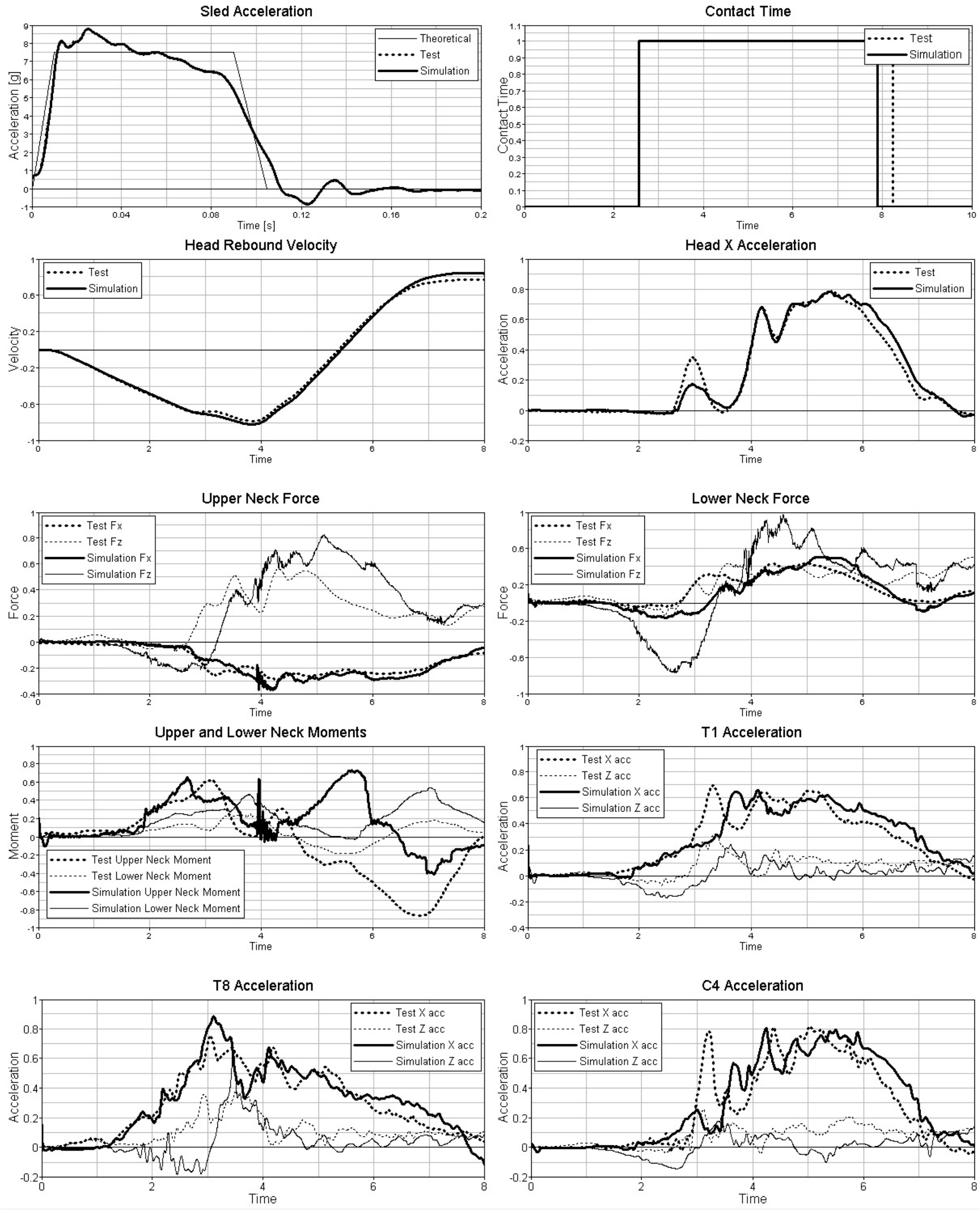


Figure 14. Comparison of the BioRID-II dummy measurements between test and simulation

	Peak time	Peak value	WIFac
Head X acc	0.998	0.995	0.76
Head Z acc	0.935	0.346	0.388
Upper Neck Fx	0.967	0.790	0.682
Upper Neck Fz	0.842	0.680	0.512
Upper Neck Mo	0.554	0.860	0.213
Lower Neck Fx	0.951	0.863	0.521
Lower Neck Fz	0.831	0.360	0.396
Lower Neck M	0.856	0.672	0.292
T1 X acc	0.805	0.953	0.567
T1 Z acc	0.932	0.739	0.298
T8 X acc	0.980	0.854	0.607
T8 Z acc	0.988	0.591	0.385
C4 X acc	0.844	0.987	0.556
C4 Z acc	0.870	0.728	0.227
L1 X acc	0.861	0.832	0.521
NIC	0.909	0.924	0.452
HRV	0.996	0.913	0.893

Table 2. Correlation between hardware and virtual simulation.

The virtual simulation was very complex. Both models (dummy and seat) needed to behave correctly alone, but also they needed to interact properly and the properties of the interaction components like foam or fabric are important. The properties of those components are going to be investigated in the future to provide good FEA models. Main CAE topics are: foam stiffness and its rate dependence, interaction between dummy and seat like friction, properties of the fabric (elasticity). The complete set of EuroNCAP variables (except for $\mathbf{N_{km}}$) is compared in Table 1.

All the variables in hardware simulation and in virtual simulation were filtered with the filters of the same class, defined by EuroNCAP protocol [3]. The values of accelerations from Table 1 were measured as 3 ms values (the highest values, which occur 3 ms or longer) [8].

To check the similarity between hardware simulation and virtual simulation curves three criteria have been used. These were the peak time, peak value and Weight Integrated Factor, which compare the areas under the curves. This method has been developed by TNO and propose in several working group dedicated to virtual testing [10].

For all the measurements except for the Upper Neck Moment the peak time is correlated in over 80%. The peak values for all accelerations and forces in X direction are correlated also in at least 79%. The values for Z direction are in general correlated not so good. For the Head Z acceleration and Lower Neck Fz force the correlation level is about 35%. Also WI Factor shows much better correlation of the results for X direction (shear) than for Z direction (tension). It suggests that the ramping behavior of the dummy, which is influenced by friction and belt system behavior, still needs more investigation and further activities in order to improve the correlation.

The EuroNCAP variables are correlated well. The start of contact time between head and head restraint system occurred at the same moment. Also the values of T1 X acceleration , Upper Neck Shear force and computed Neck Injury Criteria show very good level of correlation (the peak values differ not more than 15%).

The purpose of using the BioRID dummy model is not to have 100% correlation with test results, but to get the tendency in results, when checking different design solutions that could improve whiplash performance.

Section 6.3 shows acceptable correlation between hardware simulation and virtual simulation. Section 7.0 will show how Whiplash simulation can be use to evaluate the influence of one parameter by keeping the other fixed. We have chosen to to focus on the following 3 topics:

- influence of backset range following EuroNCAP protocol

- influence of fabric evaluated through friction coefficient between occupant and fabric

- influence of H-Point position range following EuroNCAP protocol

7. Using the Abaqus BioRID-II Dummy in the Project Work

7.1 Influence of the backset

One of the most important factors in prevention of whiplash risk is the backset – the distance between the head and head restraint system.

To compare the influence of different backsets two virtual simulations were made. One with backset of 85 mm, the second one with backset of 59 mm.

The results obtained by simulation confirmed the backset influence : 26 mm backset can lead to EuroNCAP variables changes by 30 %.

Variable	Base Simulation	Simulation Backset 85	Difference (in %)	Influence

	Backset 59 mm	mm		
Head Restraint Contact Time	2.56	3.2	+0.64 (+25%)	👎
T1 X-acceleration	0.66	0.72	+0.06 (+9.1%)	👎
Upper Neck Shear Force	0.0046	0.0046	0.0	⇔
Upper Neck Tension Force	0.82	1.02	+0.2 (+23.5%)	👎
Head Rebound Velocity	0.84	0.82	-0.02 (-2.5%)	⇔
NIC	0.83	0.80	-0.03 (-4.4%)	⇔

Table 3. Comparison of EuroNCAP variables [Backset: 59 mm and 85 mm].

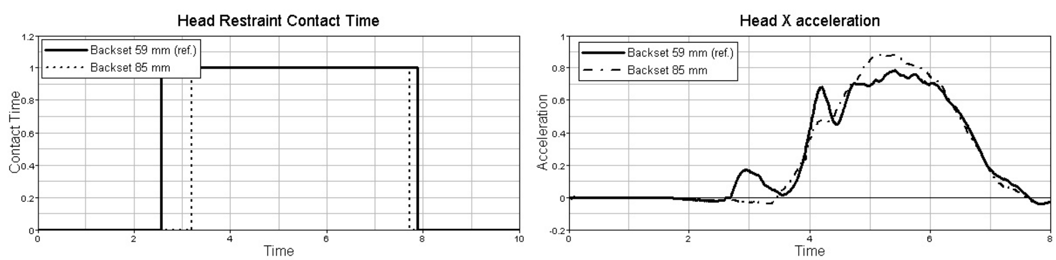


Figure 15. Comparison of results for Backset: 59 mm and 85 mm.

7.2 Fabric Influence evaluated by friction coefficient

This section will show the influence of the friction coefficient. Car seats are covered with fabric or leather. These kinds of upholstery provide substantially different friction coefficient between the seat and the dummy. Two simulations have been made with two extreme values of friction coefficient: 0.1 and 0.6, in order to analyze the whiplash performance in virtual simulations.

The analysis of the results enables to draw following conclusions: usage of very small friction coefficient makes the improvement of head rebound velocity. It's value is decreased, what assures the maximum EuroNCAP score for this variable. The head rebound velocity is influenced by slipping – the rebound phase starts much later than in the reference virtual simulation. Also the upper neck tension force is reduced. The loads to the neck are lower also due to the slipping of the dummy. However, the observed ramping may be dangerous in the later phase of impact, when the dummy's head may even fall off the headrest.

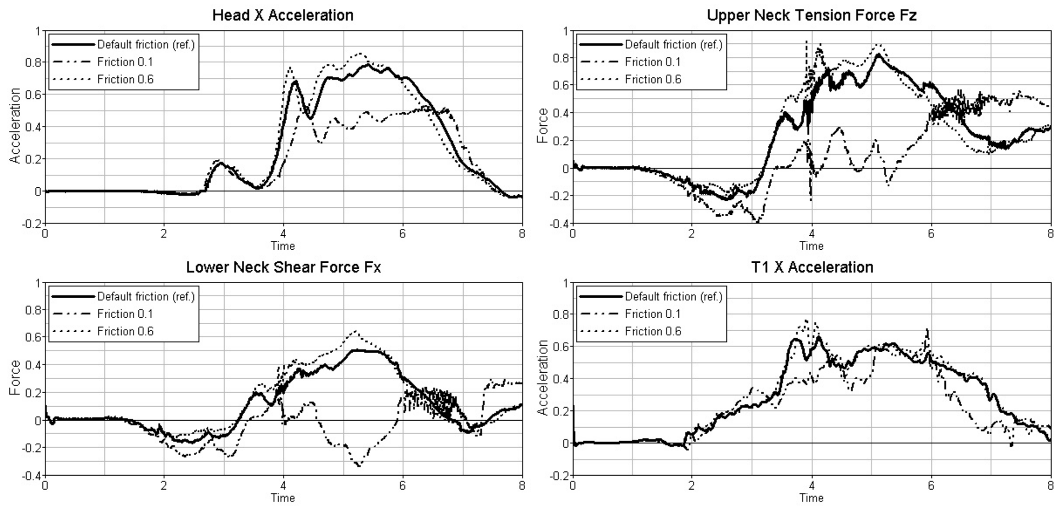


Figure 16. Comparison of results for different friction coefficients.

On the other hand, for the very high friction coefficient, the tension force in the upper neck and head rebound velocity will increase. For high friction coefficient the dummy's relative motion with respect to the seat is minimal, which increases the tension loads in the neck.

These simulations were done to give the users the feeling about how the virtual BioRID dummy behaves for such extreme values of friction coefficient.

Variable	Base (Ref.)	Friction 0.1	Difference	Influence	Friction 0.6	Difference	Influence

	Friction ~0.4		(in %)			(in %)	
Head Restraint Contact Time	2.56	2.52	-0.04	⇔	2.6	+0.04	⇔
T1 X-acceleration	0.66	0.72	+0.06 (+9.1%)	⇔	0.77	+0.11 (+16.7%)	👎
Upper Neck Shear Force	0.0046	0.0082	+0.0036 (+78.2%)	⇔	0.008	+0.0034 (+73.9%)	⇔
Upper Neck Tension Force	0.82	0.51	-0.31 (-38.1%)	👍	0.87	+0.05 (+6.1%)	⇔
Head Rebound Velocity	0.84	0.38	-0.46 (-55%)	👍	0.88	+0.04 (+4.2%)	⇔
NIC	0.83	0.54	-0.29 (-34.8%)	👍	0.85	+0.02 (+2%)	⇔

Table 4. Comparison of EuroNCAP variables for various friction coefficients.

7.3 Influence of dummy position

During dummy positioning in a hardware simulation the dummy has a certain tolerance of position in regard to the SAE J826 and HRMD dummy measurements. The H-point has a tolerance field of

20 mm (± 10 mm) in X and in Z directions, and the backset has a tolerance of 10 mm (±5mm) in the X direction [3].

When considering the X tolerance two extreme dummy positions can be defined – most forward and most rearward. These two cases were simulated, to check the influence of dummy position during the virtual test . The reference model, which was based on hardware simulation results was not in middle position. The H-point was 2 mm farther than the middle one and the backset was 2 mm closer than the middle position. It means that for every position, the dummy's spine had a different shape. The initial backset values in X direction were: 82 mm for the most rearward position and 92 mm for most forward position. The backset value for the reference virtual simulation was 85 mm.

The results show the sensitivity of the BioRID dummy to its the initial position. The most obvious change was the contact time, which started 3 ms earlier for most rearward and or 2 ms later for most forward case. In both extreme BioRID positions there would not influence much the overall EuroNCAP score. The achieved result for X acceleration in T1 in most rearward position is brought closely to the upper limit for this variable. The increase of acceleration may be explained by quicker contact between dummy's torso and rigid metal structure of the backrest. In summary, there was no significant influence on the EuroNCAP variables .

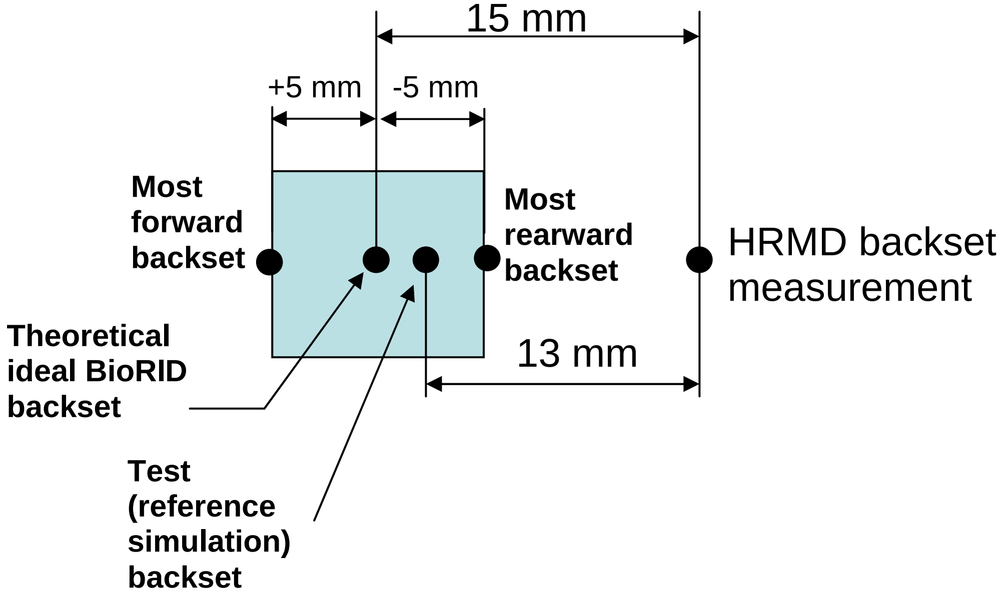


Figure 17. Tolerance field for BioRID backset and three positions used in simulations.

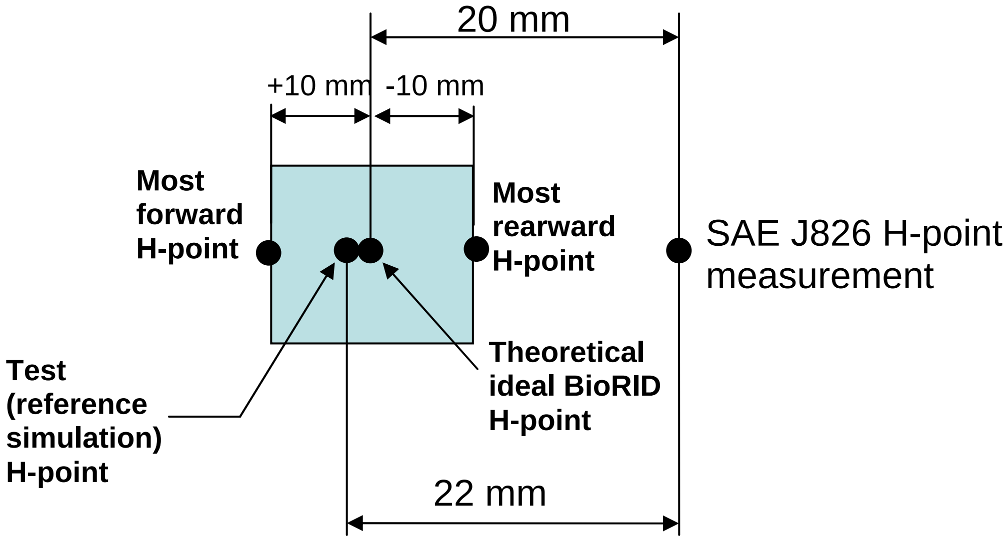


Figure 18. Tolerance field for BioRID H-point and three positions used in simulations.

Variable	Base (Ref.)	Most Forward	Difference (in %)	Influence	Most Rearward	Difference (in %)	Influence
Head Restraint Contact Time	2.56	2.64	+0.08 (+3.1%)	⇔	2.44	-0.12 (-4.7%)	⇔
T1 X-acceleration	0.66	0.71	+0.05 (+7.5%)	⇔	0.88	+0.22 (+33.3%)	👎
Upper Neck Shear Force	0.0046	0.016	+0.0114 (>100%)	⇔	0.0128	+0.0082 (>100%)	⇔
Upper Neck Tension Force	0.82	0.85	+0.03 (+2.7%)	⇔	0.88	+0.06 (+6.6%)	⇔
Head Rebound Velocity	0.84	0.86	+0.02 (+1.9%)	⇔	0.86	+0.02 (+2%)	⇔
NIC	0.83	0.65	-0.18 (-22%)	⇔	0.72	-0.11 (-13.2%)	⇔

Table 5. Comparison of EuroNCAP variables for different dummy positions

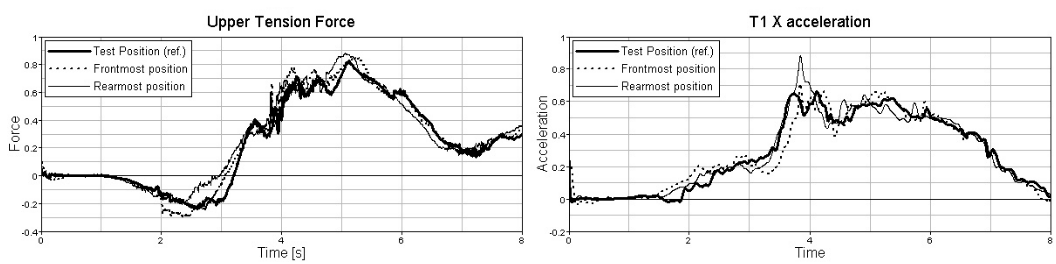


Figure 19. Comparison of results between different dummy positions

8. Conclusions

This paper has described the definition and subsequent use of a BioRID-II dummy, in the validation of the seat model for low speed rear impact crash analysis. It defined also the conditions and output/assessment variables of the EuroNCAP protocol.

Thanks to close cooperation with SIMULIA and BMW it was possible to perform a testing and validation of both BioRID-II Abaqus dummy and BMW seat model. Abaqus BioRID II dummy in version 1.9 proved to be a useful tool to support the seat design process. The correlation with test results was at a acceptable level. For almost all of the measurements and computed EuroNCAP variables a score of over 80% was achieved for peak value and peak time, what is considered as acceptable correlation and allows the model to be used in seat development process.

Furthermore the influence of backset, the influence of friction, the influence of dummy position have been shown. Next steps will cover the investigation of the foam and fabric properties. Also the pulse tolerance will be checked.

Due to very high complexity of the virtual simulations, an acceptable correlation with the hardware simulation was achieved. The Abaqus BioRID simulations with different seat modifications show a tendency in EuroNCAP scoring, without performing hardware sled tests. The aim of using the FE BioRID- II dummy is to increase the speed of the design team in response to the requirements of the customer. It shows, how important are simulations in design process at present.

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